# GAS LASER DEVICE AND EXPOSURE APPARATUS USING THE SAME

## FIELD OF THE INVENTION AND RELATED ART

This invention relates to a gas laser device such as a noble gas halide excimer laser device or ~~a~~ an $F_2$ laser device, for example. In another aspect, the invention is concerned with an exposure apparatus or a semiconductor device manufacturing method wherein such a gas laser device is used as an exposure light source.

In the field of semiconductor device production or other fields, a noble gas halide excimer laser (hereinafter, simply "excimer laser"), which is one of ~~gas lasers~~, has attracted much attention as a high power laser. As for such an excimer laser, there are an XeCl excimer laser (308 nm wavelength), a KrF excimer laser (248 nm wavelength), and an ArF excimer laser (193 nm wavelength), for example. Similarly, an $F_2$ laser (158 nm wavelength) has attracted much attention as a high power laser. Also, semiconductor device manufacturing exposure apparatuses of the step-and-repeat type or step-and-scan type having a KrF excimer laser (248 nm wavelength) as an exposure light source have already been used in practice.

In excimer lasers, a laser gas containing a noble gas and a halogen gas is sealingly stored in a

chamber, and the laser gas is once excited by ~~electric~~ electrical discharging from an electrode, provided in the chamber, whereby laser light is produced. Also, in $F_2$ lasers, ~~a~~ an $F_2$ gas is sealingly stored in a chamber, and the laser gas is once excited by ~~electric~~ electrical discharging from an electrode, provided in the chamber, whereby laser light is produced.

<u>SUMMARY OF THE INVENTION</u>

In such excimer lasers or $F_2$ lasers, it is necessary to circulate the laser gas within the chamber in order to feed the laser gas to the electric discharging field of the electrode. To this end, within the chamber, there is circulating means for laser gas circulation such as a blowing machine (blower or circulating fan), for example. If the lifetime of the blowing machine provided in the chamber is short, the operation of the laser has to be stopped frequently for replacement of the laser or blowing machine or for repair of the same. In cases where the laser is used as a light source in an exposure apparatus, it largely affects the productivity of the apparatus. Since the blowing machine is disposed within the chamber, it takes ~~a~~ much time for replacement or repair of the same.

A factor that influences the lifetime of the blowing machine may be the lifetime of bearing means

for holding a rotational shaft of blowing fans of the blowing machine. Generally, the lifetime of each bearing means is shorter with a larger load applied, in operation. Therefore, if the number of revolutions of the blowing fans is enlarged to increase the blowing power of the blowing machine, with a result of enlargement of the load applied to the bearing means for supporting the rotational shaft, it accelerates wear and shortens the lifetime of the bearing. Namely, if the blades of the blowing machine are rotated at a high speed for high frequency laser oscillation, the lifetime of the bearing means for supporting the blade rotational shaft of the blowing machine is shortened.

However, in an exposure apparatus having an excimer laser, for example, as an exposure light source, normally it is required that the excimer laser is oscillated at a high frequency for improved processing performance of the apparatus. Therefore, it is not practical to use the blowing machine at its low blowing power level for prolongation of the lifetime of the bearing. On the other hand, for the reasons described above, if replacement or repair of the excimer laser or the blowing machine occurs frequently, in an exposure apparatus having an excimer laser as an exposure light source, it leads to decreased productivity or throughput.

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Further, in gas laser devices, the lifetime of the blowing machine disposed in the chamber where the laser gas is stored should be longer than the lifetime of at least the chamber.

It is accordingly an object of the present invention to provide a gas laser device having a long lifetime and a high power.

It is another object of the present invention to provide an exposure apparatus or a device manufacturing method ~~with~~ that use ~~of~~ such a gas laser device as an exposure light source, whereby high productivity is assured.

In accordance with an aspect of the present invention, there is provided a gas laser device, comprising: a chamber for sealingly storing a laser gas therein; a discharging electrode for exciting the laser gas through ~~electric~~ electrical discharging, so that laser light is outputted from said chamber; circulating means for circulating the laser gas within said chamber so that the laser gas passing an electric discharging region of said discharging electrode is circulated in said chamber and is returned to said ~~electric~~ electrical discharging region of said discharging electrode; and control means for controlling said circulating means so that said circulating means provides different gas circulation capacities~~,~~ being different for an in-operation state in which the laser

gas is excited by ~~electric~~ electrical discharging from said discharging electrode and the laser light is outputted and for a stand-by state which differs from said in-operation state but in which laser light can be outputted.

Said control means may be operable to stop the gas circulation through said circulating means when said gas laser device is in said stand-by state. Said circulating means may include a blowing machine provided within said chamber. Said blowing machine may have a blowing blade rotatably supported within said chamber. Said laser device may comprise one of a noble gas halide excimer laser and ~~a~~ an $F_2$ laser. Said noble gas halide excimer laser may comprise one of an XeCl excimer laser, a KrF excimer laser, and an ArF excimer laser.

In accordance with another aspect of the present invention, there is provided an exposure apparatus for exposing a substrate with the laser light, comprising: a laser light source having a chamber for sealingly storing a laser gas therein, a discharging electrode for exciting the laser gas through ~~electric~~ electrical discharging, so that laser light is outputted from said chamber, and circulating means for circulating the laser gas within said chamber so that the laser gas passing an ~~electric~~ electrical discharging region of said discharging electrode is circulated in said

chamber and is returned to said ~~electric~~ electrically discharging region of said discharging electrode; a major assembly for exposing a substrate with laser light from said laser light source; and control means for controlling said circulating means so that said circulating means provides different gas circulation capacities, being different for an in-operation state in which the laser gas is excited by ~~electric~~ electrical discharging from said discharging electrode and the laser light is outputted and for a stand-by state which differs from said in-operation state but in which laser light can be outputted.

Said control means may be operable to stop the gas circulation through said circulating means when said gas laser device is in said stand-by state. Said circulating means may include a blowing machine provided within said chamber. Said blowing machine may have a blowing blade rotatably supported within said chamber. Said laser device may comprise one of a noble gas halide excimer laser and ~~a~~ an $F_2$ laser. Said noble gas halide excimer laser may comprise one of an XeCl excimer laser, a KrF excimer laser, and an ArF excimer laser.

In accordance with a further aspect of the present invention, there is provided an exposure apparatus, comprising: a laser light source having (i) a chamber for sealingly storing a laser gas therein,

(ii) a discharging electrode for exciting the laser gas through ~~electric~~ electrical discharging so that laser light is outputted from said chamber, and (iii) circulating means for circulating the laser gas within said chamber so that the laser gas passing an ~~electric~~ electrical discharging region of said discharging electrode is circulated in said chamber and is returned to said electric discharging region of said discharging electrode; a main assembly for exposing a substrate with the laser light from said laser light source; and control means for controlling said circulating means so that said circulating means provides different gas circulation capacities, being different for an exposure-operation state of said exposure apparatus in which exposure of the substrate with the laser light from said laser light source can be performed through said main assembly, and for a non-exposure-operation state of said exposure apparatus.

Said control means may be operable to increase the gas circulation capacity of said circulating means in response to a start of an exposure job in which the exposure operation is performed through said main assembly. Said control means may be operable to hold gas circulation through said circulating means stopped before a start of the exposure job. Said circulating means may include a blowing machine provided within said chamber. Said blowing

machine may have a blowing blade rotatably supported within said chamber. Said laser light source may comprise one of a noble gas halide excimer laser and ~~a~~ an $F_2$ laser. Said noble gas halide excimer laser may comprise one of an XeCl excimer laser, a KrF excimer laser, and an ArF excimer laser.

In accordance with a further aspect of the present invention, there is provided a semiconductor device manufacturing method in which a pattern is lithographically transferred onto a substrate by use of any one of the exposure apparatuses as described above.

These and other objects, features and advantages of the present invention will become more apparent upon a consideration of the following description of the preferred embodiments of the present invention taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic view of an exposure apparatus with a gas laser device, according to an embodiment of the present invention.

Figure 2 is a longitudinal section of a chamber of the gas laser device.

Figure 3 is a lateral section of the chamber of the gas laser device.

Figure 4 is a schematic view for explaining details of a rotational shaft of a blower.

Figure 5 is a flow chart for explaining operation with the gas laser device of this embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 shows an exposure apparatus according to an embodiment of the present invention. Denoted in Figure 1 at 1 is a main assembly of a step-and-repeat or step-and-scan exposure apparatus, called a stepper. Denoted at 2 is a console with which an operator, for example, can apply a job command to a control system (not shown) in the exposure apparatus main assembly 1, for controlling the operation of the main assembly. Denoted at 3 is a laser light source having a gas laser device which is based on a noble gas halide excimer laser (called "excimer laser"), or ~~a~~ an $F_2$ laser, for example. Examples of such an excimer laser may be an XeCl excimer laser (308 nm wavelength), a KrF excimer laser (248 nm wavelength), and an ArF excimer laser (193 nm wavelength). The following description will be made ~~on~~ of an example wherein the laser light source 3 uses a noble gas halide excimer laser.

The main assembly 1 of the exposure apparatus comprises a beam shaping optical system 4 for rectifying, into a desired beam shape, the sectional

shape of laser light from the laser light source 3, along the path of laser light (laser beam). The main assembly further comprises a variable ND filter 5 for adjusting the intensity of laser light, and an optical integrator 6 for dividing the laser light and superposing the divided beams one upon another for uniform illuminance upon the surface of a reticle 12. The main assembly further comprises a condenser lens 7 for collecting laser light from the optical integrator 6, and a beam splitter 8 for directing a portion of the laser light from the condenser lens 7 toward a photodetector 15. The main assembly further comprises a masking blade 9 disposed at a position where the laser light is collected by the condenser lens 7 and for regulating the range on the reticle 12 surface to be irradiated with the laser light. The main assembly further comprises an imaging lens 10 for forming an image of the masking blade 9 upon the reticle 12, and a mirror 11 for directing the path of laser light toward the optical axis direction of a projection lens 13.

The reticle 12 can be illuminated with laser light projected by the laser light source 3 and passed through the illumination optical system having optical components such as described above. With this illumination, a pattern of the reticle is projected by the projection lens (projection optical system) 13

onto one of different exposure shot areas on a semiconductor wafer (substrate) in a reduced scale of 1/2 to 1/10, whereby the pattern is lithographically transferred thereto. The wafer 14 can be moved two-dimensionally along a plane perpendicular to the optical axis of the projection lens 13, by means of a movable stage (not shown). As the exposure of a certain shot area on the wafer is completed, the wafer is moved to the position where the pattern of the reticle 12 is to be projected by the projection lens 13 onto a next shot area on the wafer.

Denoted at 16 is signal processing means for processing a photoelectrically converted signal, having been photoelectrically converted by the photodetector 15 and corresponding to the intensity of the laser light. Through integration of photoelectrically converted signals, a signal for controlling the exposure amount can be produced. A control signal obtained with the signal processing through the signal processing means 16 is fed back to a controller 31 of the laser light source 3. In accordance with this control signal, the controller 31 controls the subsequent light emission by the laser gas in the chamber 30 of the excimer laser 3.

Figure 2 is a longitudinal section of the chamber 30 of the excimer laser 3. Denoted in Figure 2 at 32 is a pair of discharging electrodes which are

connected to a high voltage source (HV), not shown. On the basis of the electrical ~~electric~~ discharging from the discharging electrodes 32, the laser gas LG portion which is placed in the discharging region 33 between the discharging electrodes 32 is excited, whereby laser oscillation is executed in a known manner. The electrical ~~electric~~ discharging from the discharging electrodes 32 is repeated periodically, such that as shown in Figure 3 the excimer laser 3 provides periodic outputs or oscillation of laser light 40.

The laser gas LG within the chamber 30 of the excimer laser 3 is circulated in the chamber 30 in directions (counterclockwise in Figure 2) denoted by arrows in the drawing, by means of a blower or circulating fan 34 of a blowing machine (circulating means), which is provided within the chamber 30. Thus, the laser gas LG passing the electrical ~~electric~~ discharging region 33 of the discharging electrodes 32 is circulated in the chamber 30 and is moved back to the discharging region 33 of the electrodes 32. During this circulation process, the laser gas LG passes around a heat exchanger 35 so that it is cooled to a desired temperature. Within the heat exchanger 35, there is a flow of temperature regulating fluid such as ~~a~~ temperature controlled water or air, which is supplied from a temperature adjusted fluid supplying device (not shown) disposed outside the chamber 30.

As shown in Figure 3, there are windows 36 and 37 before and after the ~~electric~~ electrical discharging region 33 in the chamber 30 of the excimer laser 3. The laser light produced at the discharging region 33 is amplified while being passed through the windows 36 and 37 and being reflected by an output window (half mirror) 38 (which is a laser output end) and a total reflection mirror 39. A portion of the thus amplified laser light is outputted from the output window (half mirror) 38, whereby laser light 40 is emitted as exposure light. During this process, the blower 34 is continuously rotated to circulate the laser gas LG within the chamber 30 as described above. When the laser oscillation frequency has to be increased, the number of revolutions of a blower drum 340 (Figure 4) of the blower 34 is increased to enhance the blowing power of the blower accordingly.

Around the blower drum 340, there are a number of blades (blowing fans) 345, as shown in Figure 2, mounted. With the rotation of the blower drum 240, these blades 345 operate to circulate the laser gas LG within the chamber 30. The blower drum 340 has a rotational shaft 341 which is rotatably supported by bearing means (rotational shaft supporting means) such as by ball bearing 342, for example. The lifetime of the ball bearing 342 changes with the load applied to the ball bearing 342, and the load changes with the

rotation speed or rotation time of the blower drum 340.

The operation of this embodiment will now be described with reference to the flow chart of Figure 5. As a voltage source for the excimer laser 3 (laser light source) is powered on at step S0, the sequence goes to a warming-up state at step S2 while the laser is kept in a laser-off state at step S1. In the warming-up state at step S2, the ~~electric~~ electrical discharging from the discharging electrodes 32 is not initiated, and also the blower 34 is kept stopped. The remaining functions are operated such that, in this state, in response to a start of ~~electric~~ electrical discharging from the discharging electrodes 32, the laser emission can be executed promptly.

In this state, if at step S3 an exposure job start signal, for example, is applied from the console 2 of Figure 1 to the stepper main assembly 1 and the excimer laser 3, the ~~electric~~ electrical discharging from the discharging electrodes 32 of the excimer laser 3 is initiated. Simultaneously, the blower 34 starts its rotation to initiate circulation of the laser gas LG in the chamber 30. Thus, the excimer laser is brought into a laser-on state at step S4, such that laser light 40 is produced from the output window 38 of Figure 3. On the other hand, within the stepper main assembly 1, a wafer 14 introduced into the main

assembly 1 is taken out of a wafer cassette, and it is placed on a wafer stage (not shown) which is placed at an exposure position below the projection lens 13. Additionally, after execution of a predetermined alignment operation with respect to a reticle 12, the exposure process is performed at step S5 by using the laser light 40 as exposure light. The exposure operation in the stepper main assembly 1 is repeatedly and sequentially performed until exposures of all wafers 14 set beforehand are completed.

Until the exposure operation at step S5 is completed, the blower 34 in the chamber 30 continues its rotation to continue its blowing operation. During this period, at step S4, the laser controller 31 continuously detects the rotation speed (number of revolutions) of the blower 34. If there is any error in the number of blower revolutions, the ~~electric~~ electrical discharging from the discharging electrodes 32 is discontinued. Also, the blower 34 rotation is stopped. By this, the laser goes back to the warming-up state at step S2. ~~In~~ On that occasion, the laser controller 31 signals the error in the laser 3 to the console 2, such that the console 2 applies a signal to the stepper main assembly 1 to stop the job being executed, whereby the exposure operation in the stepper main assembly 1 is stopped.

If, on the other hand, any error in the

number of revolutions is not detected, the exposure operation at step S5 is continued, and the exposure job is performed until exposures of all the wafers 14 set in the stepper main assembly 1 are completed. When, at step S6, exposures of all the wafers 14 in the stepper main assembly 1 are completed and the exposure job thereto is accomplished, the stepper main assembly 1 signals the exposure job completion to the console 2. In response, the console 2 signals the exposure job completion in the main assembly 1 to the controller 31 of the laser 3. In response, the laser controller 31 stops the blower 34 rotation and, additionally, it stops the ~~electric~~ electrical discharging from the discharging electrodes 32 whereby laser oscillation from the excimer laser 3 is stopped.

In this embodiment, the blower 34 rotates only in a period in which an exposure operation is performed in the stepper main assembly 1 or in a period in which the excimer laser 3 provides laser light oscillation. On the other hand, in the stepper main assembly 1, there is a job, other than the exposure job, which necessitates oscillation of the excimer laser 3 for measurement of illuminance non-uniformness upon a reticle 12 or a wafer 14, or for temperature stabilization of the projection lens 13, for example. During a period in which such a job is executed, the blower 34 is rotated. In accordance

with this embodiment of the present invention, the period of term for replacement or repair of the blower 34 or bearing means 342, that is, the lifetime of it, can be prolonged. Particularly, the lifetime of the blower 34 may be made longer than that of the chamber 30.

While the invention has been described with reference to the structures disclosed herein, it is not confined to the details set forth and this application is intended to cover such modifications or changes as may come within the purposes of the improvements or the scope of the following claims.